An improved glimpse into earthquake activity in northeastern Alaska

Helena Buurman
Geophysical Institute, University of Alaska Fairbanks
04 September 2018

ABSTRACT

The northeastern Brooks Range is long known to be seismically active, but meaningful analysis of the earthquake activity has been limited by the lack of instrumentation. The seismic record in the area dates back to the mid-1970s, and shows a broad northeast-trending zone of earthquake activity. Improvements made in the past 20 years to the permanent seismic network along with new data collected by the temporary USArray network of seismometers located throughout northeastern Alaska have dramatically lowered the earthquake detection threshold in the area. It is now possible to identify patterns within the earthquake data including spatial distribution and occurrence rates, which indicate the presence of previously unrecognized active fault systems. I highlight several such features within the data: a 110 km (60 mi) line of recurring earthquakes near the village of Beaver that strongly suggest a singular fault system; a cluster of earthquakes near the village of Venetie that are likely occurring on a complex active fault system; a years-long mainshock-aftershock sequence of earthquakes near the Draanjik River that began in 2006; and two swarms separated by 50 km (30 mi) in distance and 7 years near the Hulahula River.

GEOGRAPHIC SETTING

Seismicity in the eastern Brooks Range follows a broad 250 km-wide (155 mi) zone of earthquake activity that trends southwest to northeast. I refer to this region as the ANWR seismic zone after the Arctic National Wildlife Refuge that encompasses much of the area (Figure 1). The northern limit of the ANWR seismic zone extends into the Beaufort Sea as far as the mapped quaternary faults located approximately 30 km (18 mi) offshore (Figure 2). Occasional earthquakes further out in the Beaufort Sea indicate that some seismicity persists beyond this point but at a much lower rate. To the south, the ANWR seismic zone ends at the east to west-trending Tintina Fault, a major right-lateral strike slip fault that parallels the Denali Fault 300 km (180 mi) to the south. While the surface expression of the Tintina Fault is mapped only as far west as 147°W, the distribution of microseismicity (Figure 1) indicates that the Tintina fault system is seismically active at least 160 km (100 mi) west than mapped, reaching as far as 150°W. Only two other active faults are mapped between the Tintina fault and the offshore faults in the Beaufort Sea (Figure 2). Given the extent of seismicity in the area, however, this apparent lack of active faults can be attributed to limited geologic field mapping, which is due in large part to the remoteness of the area and the challenges this presents for undertaking geologic mapping studies (M. Wartes, pers. Comm. 2018).

The ANWR seismic zone is a distinct feature within the large scale seismicity of Alaska. It has long been recognized as a significant zone of earthquake activity, and has been attributed to far-field deformation from the subduction of the Pacific plate by a variety of studies (e.g., Mazzotti and Hyndman, 2002; Leonard et al., 2008; Mazzotti et al., 2008).

HISTORY OF SEISMIC MONITORING

Seismic monitoring around the ANWR seismic zone began in the early 1970s with the installation of a single station located at Fort Yukon and the subsequent addition of the US Air Force's Burnt Mountain seismic array in the southern foothills of the eastern Brooks Range. The minimum magnitude of earthquakes in the region fluctuated between 2.5 and 3 until 1987, when data processing at the Alaska Earthquake Center was switched from analog to digital. This change dropped the minimum magnitude detected earthquakes to 1.8. Beginning in 1999, the station instrumentation to the south of the ANWR seismic zone were transitioned from short-period analog to broad-band digital, which further lowered the minimum magnitude of detected earthquakes to around 1.2.

Station coverage around the ANWR seismic zone remained unchanged until 2004, when a new permanent (digital broadband) station was installed at Coldfoot, bringing the number of stations within an area the size of Wyoming to a grand total of 3. This new Coldfoot station lowered the earthquake detection threshold for the entire region, resulting in a notable increase of smaller earthquakes with magnitudes as low as 1 in the seismic record (see Figure 3). The installation of 3 additional broadband stations along the northern Trans Alaska Pipeline in 2008 further improved the detection threshold. This is the baseline permanent network that is still in operation today.

A number of temporary networks have contributed data to the seismic record of the northeastern Brooks Range. Economic interest in the region, primarily in onshore and offshore natural resource development on the North Slope, motivated several small-scale temporary deployments of up to 9 instruments at a time during the 1970s and 1980s (e.g., Gedney et al., 1977). Although these temporary networks substantially increased the number of stations operating in the region, their contributions to the earthquake record were hampered by the harsh environment that yielded incomplete or unusable data (e.g., Biswas, 1977).

By far the greatest impact to the seismic record has come from the USArray temporary network. Beginning with test stations in 2013 and 2014, the USArray project has added 32 new stations in and around the northeastern Brooks Range spaced at approximately 85 km (53 mi) intervals (Figures 1 and 3). The USArray network was designed to have a 3-year life-span, with the majority of data being collected between 2017 and 2020. This study uses all available data through January 01, 2018.

SEISMICITY

Earthquakes have been recorded in the ANWR seismic zone since regional monitoring began in the early 1970s. Although the seismic record for earthquakes less than magnitude 2 has, until recently, been poor to non-existent, earthquakes with magnitudes 3 and greater have been recorded for decades, albeit with highly variable accuracy. The ANWR seismic zone experiences one magnitude 5 or greater earthquake every 8 years. These potentially damaging earthquakes have occurred throughout the region, and do not appear to be clustered in any one specific area.

Earthquake activity is highly localized in certain regions of the ANWR seismic zone. The most prominent feature in the seismicity map of Figure 1 is the clearly defined line of earthquakes along the active Tintina fault. A second line of earthquakes parallel to the western section of the Tintina fault and ~40 km to the north is also clearly visible. Earthquakes along this line have recurred regularly at (median) rates of 1 earthquake per month since 2008 (when the current digital network was achieved). These earthquakes were most likely occurring prior to 2008, but were too small to be detected and accurately located by the sparse monitoring network. The linear distribution of these earthquakes and their persistence through time suggest the presence of a singular well-defined fault. suggests that they occurred on a previously unrecognized fault, which I refer to as the Beaver fault after the village it passes beneath. The feature parallels but does not connect to the Tintina fault, suggesting it is not a splay feature. If this seismicity defines a singular fault, the approximate length of 110 km (60 mi) suggests it could be capable of earthquakes in the range of magnitude 7.

There are other pockets of earthquake activity in the ANWR seismic zone that do not follow the well-defined linear trends typical of active faults but that are nonetheless persistent throughout the seismic record. I refer to these features as earthquake clusters. The Venetie cluster is the largest earthquake cluster in the ANWR seismic zone, extending 150 km (100 mi) NNE from the Beaver fault across an area approximately 70 km (45 mi) wide (Figure 1). When the network coverage expanded in 2008, earthquakes below magnitude 2 became a regular feature in the catalog, occurring at (median) rates of 2 per month (Figure 3). These earthquakes are broadly grouped along 3-4 individual lines suggesting that the Venetie cluster is in fact a series of smaller faults. An earthquake relocation analysis could well resolve this ambiguity, but it is beyond the scope of this report to do so.

Not all earthquake activity in the ANWR seismic zone has been continuous throughout the seismic record, and there are several regions where seismicity has increased suddenly and persisted for months to years before returning to its previous rate. When the increase in earthquake activity follows a larger ‘mainshock’ earthquake, the seismicity can be characterized as a mainshock-aftershock sequence. The most notable mainshock-aftershock sequence recorded in the ANWR seismic zone occurred 100 km (60 mi) north and east of the Tintina fault and south of the village of Chalkyitsik, which I refer to as the Draanjik sequence after the Draanjik River that flows through this otherwise uninhabited area. Infrequent magnitude 2-3 earthquakes have occurred throughout the seismic record at rates of less than one earthquake per year, and some magnitude 1-2 earthquakes were recorded after the installation of the Coldfoot station in 2004. The Draanjik River sequence began with a magnitude 5.1 earthquake in February 2006, and was followed by 120 earthquakes with magnitudes ranging from 2.5-4.9 during the first month. The sequence continued with multiple earthquakes per month recorded through January 2008, including a group of four earthquakes with magnitudes 4.1-4.4 that occurred within a week in August 2006. Seismicity has remained elevated in this area since January 2008, with (median) rates of 1 earthquake per month. Improvements to the baseline monitoring network between the start and end of this sequence may account for this apparent continuation of the sequence, and it is possible that magnitude 1-2 earthquakes occurred regularly prior to 2006 but were below the detection threshold. If this is the case, then the Draanjik sequence might better be named the Draanjik cluster, in keeping with the nomenclature. With no mapped faults in the region, it is not clear what processes are governing this on-going activity. There has long been speculation of an active fault system along the Porcupine River to the north (e.g., Grantz,1966; Estabrook et al., 1988), but the Draanjik River sequence is located 100 km (60 mi) to the south and is therefore not likely related.

When an increase in earthquake activity is not preceded by a single, large ‘mainshock’ earthquake, I refer to it as an earthquake swarm. Two earthquake swarms stand out in the seismic record, having occurred within 50 km (30 mi) of each other near the Hulahula River in the northern region of the ANWR seismic zone but with start times separated by 7 years (Figure 1). Neither swarm occurred on a known fault system, but their presence indicates that there must be unmapped active faults in the northern ANWR seismic zone. The North Hulahula swarm began in April 2007 as a series of earthquakes ranging in size from magnitude 2-4, with one magnitude 5.0 that occurred on April 28. Several of these earthquakes were felt in Kaktovik, located 60 km (37 mi) to the northeast. Activity during the North Hulahula swarm was most vigorous during the first month with 62 earthquakes located in April 2007, and activity lasted through August of that year when the (median) rate of earthquakes returned to its previously level of 0-2 per month. The South Hulahula swarm occurred less than 50 km (30 mi) to the south from July 2013 to June 2014. The rate of earthquake activity returned to the pre-swarm rate of 0-2 earthquakes per month by June 2014, but it is worth noting that this ‘background’ rate increased to 1-3 earthquakes per month with the addition of USArray stations in the summer of 2016. Although it was longer-lasting than the North Hulahula swarm, the largest magnitude to be recorded during the South Hulahula swarm was only 4.6.

SUMMARY

Improvements in monitoring have revealed a rich and complex pattern of earthquake activity within the ANWR seismic zone. It is now possible to delineate fault-like structures from the distribution of small earthquakes in areas where faults are otherwise not mapped. The data also show that some regions of the ANWR seismic zone are more frequently active than others, again suggesting there are more fault systems than the current fault maps indicate. These initial observations will hopefully inspire future analyses of the seismicity that can enhance what little knowledge currently exists about the active faulting and earthquake hazards in one of the last corners of the nation to benefit from basic earthquake monitoring capabilities.

ACKNOWLEDGEMENTS

The hypocenter data presented are a product of the Alaska Earthquake Center. Maps were generated by Lea Gardine. This study benefited from discussions with Marwan Wartes and Justin Strauss, and reviews by Michael West and Natalia Ruppert.

REFERENCES

Biswas, N.N., 1977, Seismicity studies in northeast Alaska by a localized seismographic network, Geophysical Institute Report, University of Alaska Fairbanks, 22 pp.

Estabrook, C., D.B. Stone and J.N. Davies, 1988, Seismotectonics of northern Alaska, Journal of Geophysical Research, V93 issue B10, https://doi.org/10.1029/JB093iB10p12026.

Gedney, L., N. Biswas, P. Huang, S. Estes, and C. Pearson, 1977, Seismicity of Northeast Alaska, Geophysical Research Letters, V4, no. 5, pp. 175-177.

Grantz, A., 1966, Strike-slip faults in Alaska: U.S. Geological Survey Open File Report: Technical Data Unit classification number 267, 82 p.

Koehler, R.D., 2013, Quaternary Faults and Folds (QFF): Alaska Division of Geological & Geophysical Surveys Digital Data Series 3, http://doi.org/10.14509/qff.

Leonard, L.J., S. Mazzotti, and R.D. Hyndman, Deformation rates from earthquakes in the northern Cordillera of Canada and eastern Alaska, J. Geophys. Res, 113, B08406, doi:10.1029/2007JB005456, 2008.

Mazzotti, S., L J. Leonard, R. D. Hyndman, and J. F. Cassidy. Tectonics, Dynamics, and Seismic Hazard in the Canada–Alaska Cordillera, Active Tectonics and Seismic Potential of Alaska Geophysical Monograph Series 179, 10.1029/179GM17

Mazzotti, S., and R.D. Hyndman, Yukutat collision and strain transfer across the northern Canadian Cordillera. Geology, 30, 495-498, 2002.

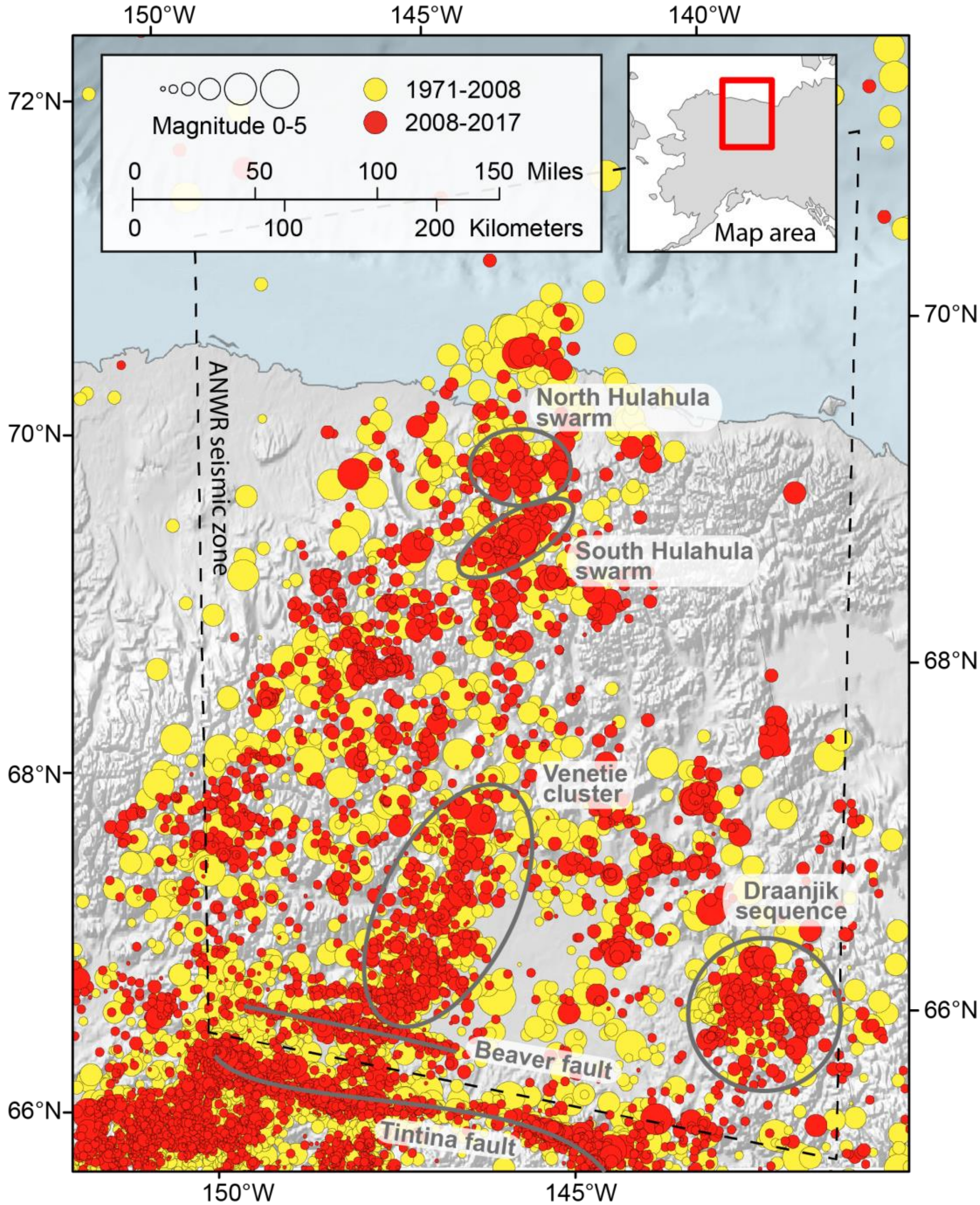

FIGURE 1: Map showing earthquake activity in northeast Alaska. The yellow circles indicate earthquakes that occurred prior to April 2008, and the red circles are earthquakes from April 2008 onwards, when the ‘backbone’ monitoring network can be considered complete. The dashed box indicates the extent of the ANWR seismic zone.

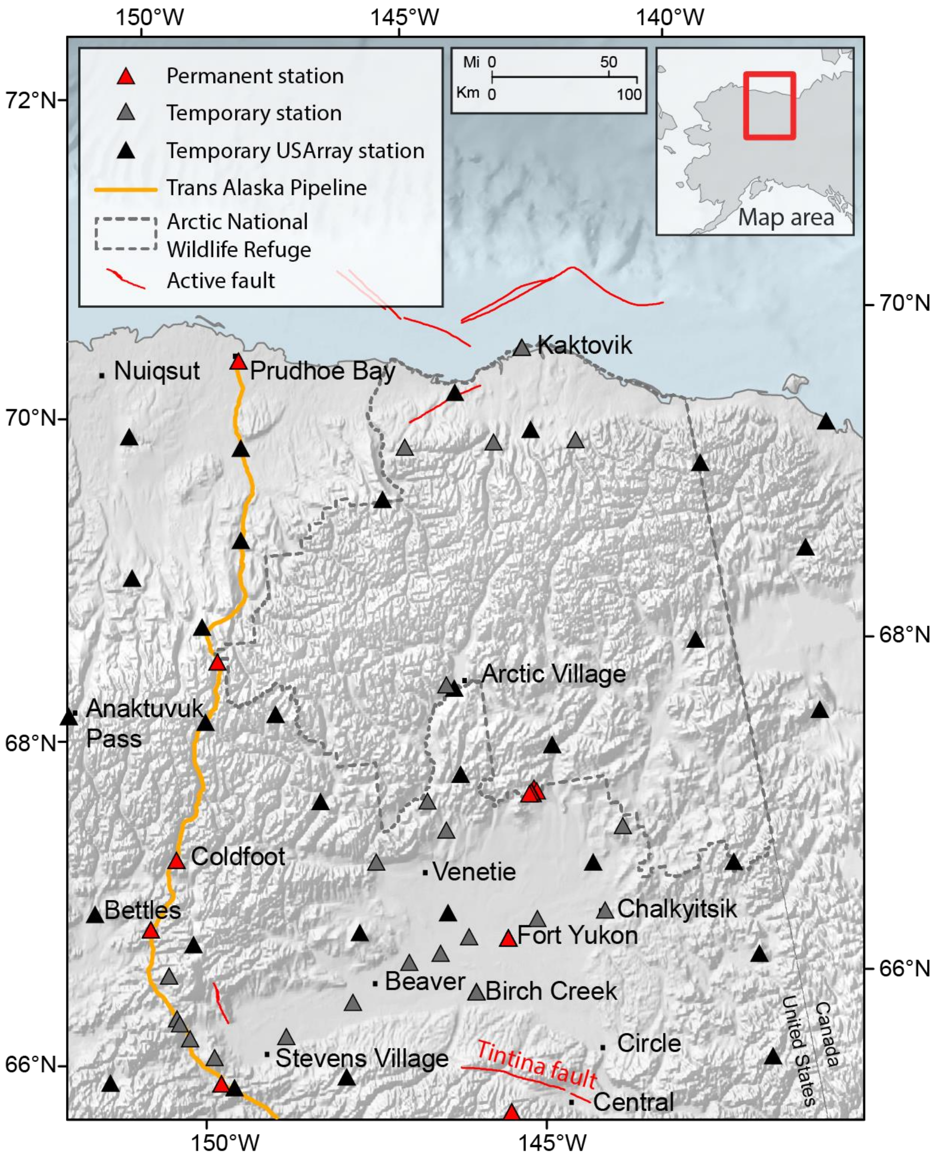

FIGURE 2: Map showing the geographic setting, mapped quaternary faults (Koehler et al., 2013), and historic station coverage around the ANWR seismic zone.

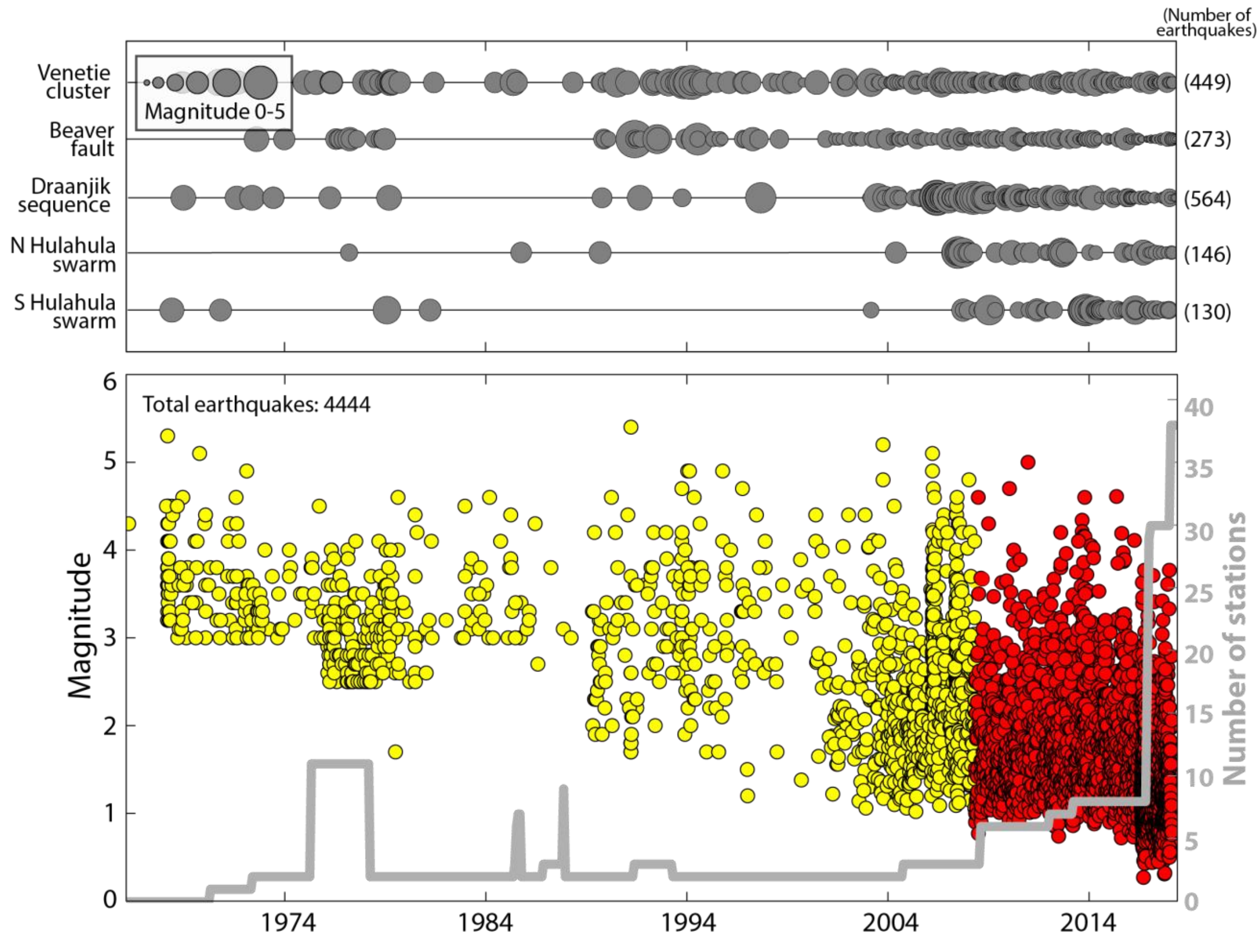

FIGURE 3: Earthquake magnitude and station coverage through time in the ANWR seismic zone. Top: Earthquake occurrences within different regions of the ANWR seismic zone. The extent of each of these regions is shown in Figure 1. Bottom: Earthquake magnitudes through time (left axis), with yellow indicating earthquakes located before the baseline permanent network was installed in 2008, and red for earthquakes located after that date. The solid grey line indicates the number of stations operating in the area between longitude 151°W and 131°W, and latitude greater than 66°N (right axis). I consider the Burnt Mountain array as one station, since this is how it is used for earthquake location purposes.